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Sennowitz

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[54] **ELECTRICAL DISCHARGE MACHINING POWER SUPPLY WITH PROTECTIVE SYSTEM FOR OUTPUT SWITCH FAILURE**

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[73] Assignee: **Colt Industries Operating Corp.,** Davidson, N.C.

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[21] Appl. No.: **221,738**

Related U.S. Application Data

[60] Division of Ser. No. 74,997, Sept. 24, 1970, Pat. No. 3,665,144, which is a continuation-in-part of Ser. No. 874,574, Nov. 6, 1969, Pat. No. 3,548,142, which is a continuation-in-part of Ser. No. 699,443, Jan. 22, 1968, Pat. No. 3,524,036.

[52] **U.S. Cl.**..... **219/69 S,** 219/69 C, 219/69 G

[51] **Int. Cl.**..... **B23p 1/08,** B23p 1/14

[58] **Field of Search**..... 219/69 C, 69 S, 69 G

[56] **References Cited**

UNITED STATES PATENTS

3,665,144 5/1972 Sennowitz..... 219/69 C X

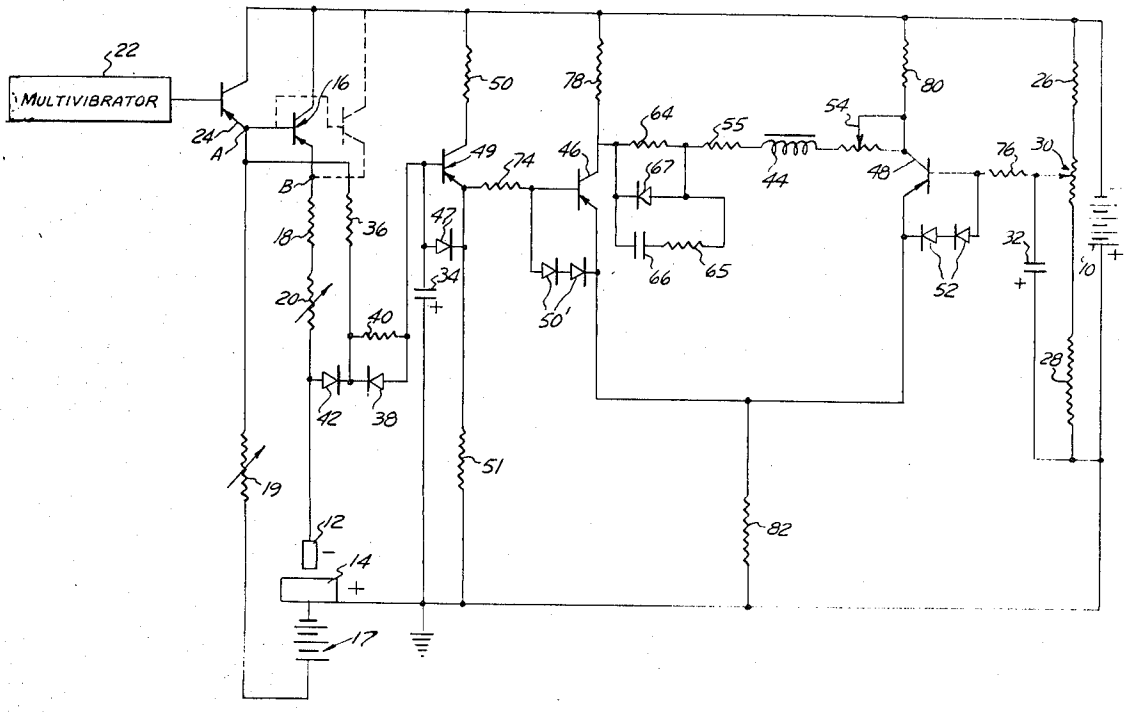
Primary Examiner—R. F. Staubly

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[57] **ABSTRACT**

A protective system for an electrical discharge machining power supply circuit including a periodically operated electronic output switch or bank of output switches and a drive stage therefor. A sensing network is connected between the output stage and the gap. Responsive to failure of one or more of the output switches and short circuiting of the gap, the remainder of output switches are biased off and there is provided an interruption of down-feed signal in the servo feed control circuit causing a back-off of the servo system until the "failed" switch has been replaced in the circuit.

10 Claims, 2 Drawing Figures



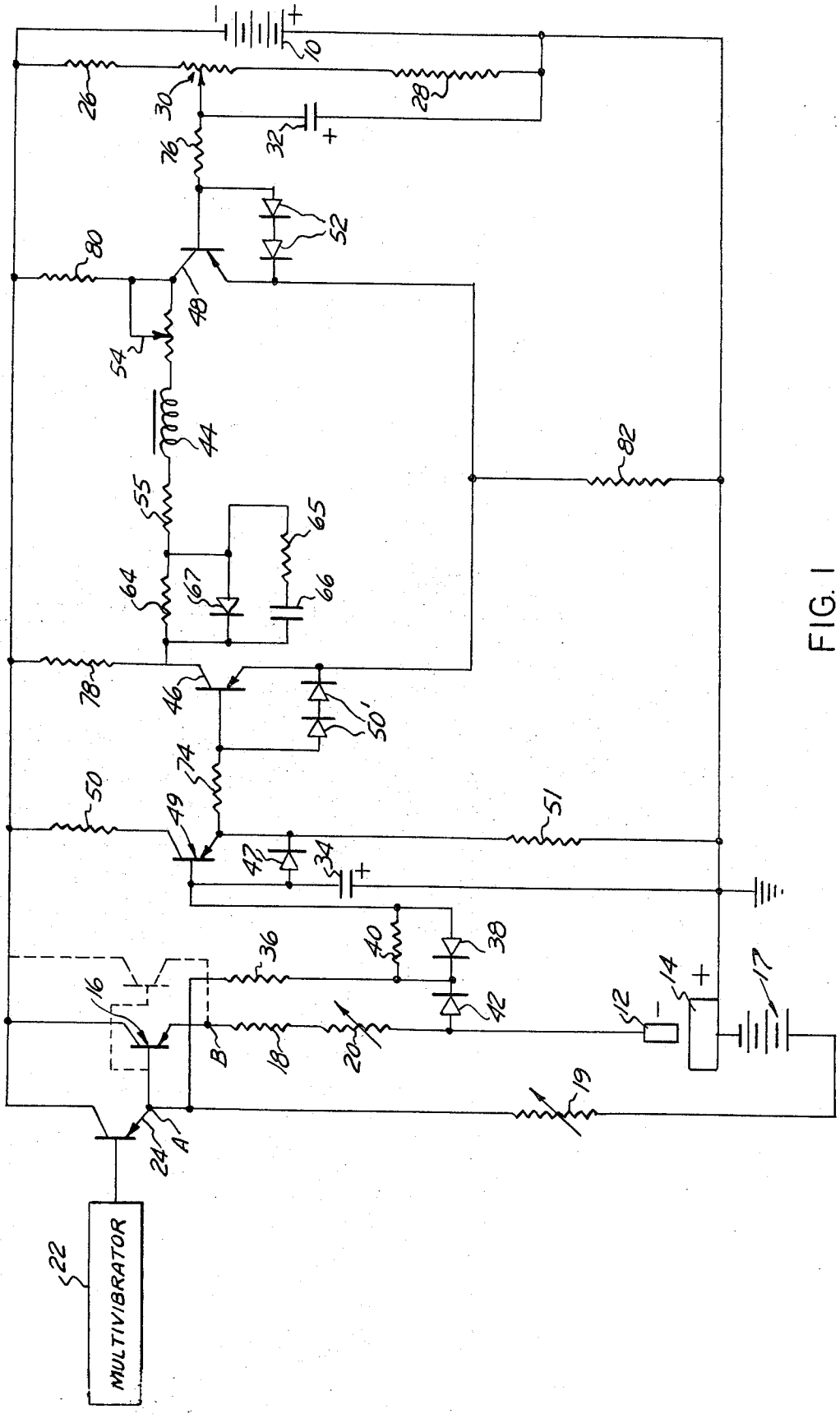

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MULTIVIBRATOR

FIG. 1

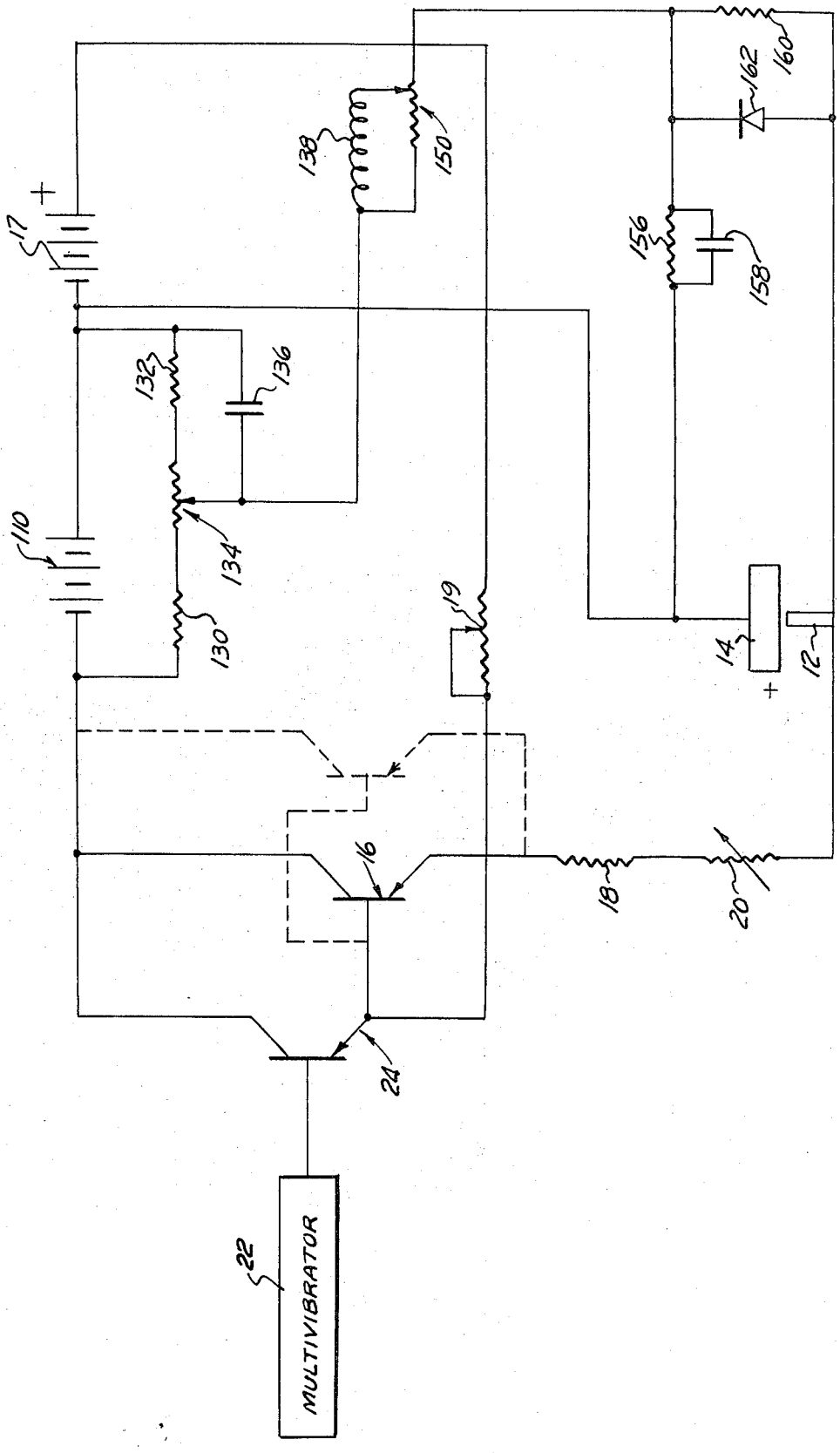

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MULTIVIBRATOR

FIG. 2

ELECTRICAL DISCHARGE MACHINING POWER SUPPLY WITH PROTECTIVE SYSTEM FOR OUTPUT SWITCH FAILURE

CROSS REFERENCE TO RELATED APPLICATIONS AND PATENTS

This application is a divisional application of my copending U.S. Pat. application No. 74,997 for "Electrical Discharge Machining Power Supply With Protective System for Output Switch Failure," filed on Sept. 24, 1970, now U.S. Pat. No. 3,665,144 issued on May 23, 1972, which application is a continuation-in-part of my U.S. Pat. application No. 874,574 filed on Nov. 6, 1969 for "Gap Short Circuit Control System for Electrical Discharge Machining Apparatus," now issued as U.S. Pat. No. 3,548,142, which patent in turn is a continuation-in-part of my U.S. Pat. application No. 699,443 filed Jan. 22, 1968 for "Servo Control Circuit for Electrical Discharge Machining Apparatus," now issued as U.S. Pat. No. 3,524,036.

BACKGROUND OF THE INVENTION

The field to which my invention relates is that known as electrical discharge machining, hereinafter sometimes referred to as EDM, in which material is removed from an electrically conductive workpiece by the action of electrical gap discharges between a tool electrode and the workpiece. These discharges are provided through an electronic pulse generator in which an electronic output switch, such as a semiconductor switching device, is alternately triggered to turn it on and off and thus periodically connect a power source to the gap to cause passage of machining power pulses across the machining gap. An electrode or workpiece servo feed is employed to maintain an optimum gap spacing between electrode and workpiece as metal removal progresses. A dielectric coolant, such as kerosene or transformer oil or the like, is circulated continuously through the gap during machining operation. A servo control circuit is required which is capable of providing a relatively constant gap under both roughing and finishing conditions as the material is being removed from the workpiece. Backup and down-feed are provided at appropriate times to maintain an optimum gap spacing. Related to that problem is the situation arising from gap short circuit condition when the output switch or one of the switches in the output switch bank fails with its principal electrodes in a shorted condition. This results in a continuous discharge across the gap. This continuous discharge does not permit transfer from point to point on the workpiece as is required for normal machining. The switch short circuiting can be partial or complete and can arise from internal damage, thermal runaway, high voltage transients or other circuit malfunctions. Prolongation of this condition can cause damage to both electrode and workpiece. I have found that this condition can best be alleviated by causing servo backup and, optionally, at the same time, biasing off the remainder of the output switches so long as the failed output switch or switches remain in the circuit.

SUMMARY OF THE INVENTION

My invention provides a protective system operable in an electronic switch operated EDM power supply. By "electronic" switch, I mean any electronic control device having three or more electrodes comprising at least two principal or power electrodes acting to control current flow in the power circuit, the conductivity between the principal electrodes being controlled by a control electrode within the switch whereby the conductivity of the power circuit is controlled statically or electrically without movement of mechanical elements within the switch. Included in this definition are electronic tubes, transistors and like devices. The output switches are biased "off" upon failure of one or more of their number. At the same time, a normal down-feed signal from the gap is inhibited and a backup bias is used to initiate an electrode or workpiece withdrawal from the gap, which withdrawal is maintained until the failed switch is removed and replaced.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a combined schematic and diagrammatic showing of my invention; and

FIG. 2 is a schematic showing with a modification of the servo control portion of that circuit.

DETAILED DESCRIPTION

The electrical discharge machining power supply of FIG. 1 includes a main machining power source **10.** Machining power pulses are passed to a gap between a tool electrode **12** and a workpiece **14** through periodic operation of an output transistor **16** which has its power electrodes, namely, its collector and emitter, in series between the power source **10** and the gap. A number of transistors **16** may be connected in parallel to provide an output bank of the required current conducting capability. The manner in which additional transistors are connected is shown in dash line representation. The output transistor **16** is normally biased "off" in the absence of triggering pulses being supplied to its base. The "off" bias is provided to the base of transistor **16** from a separate bias source **17.** Bias voltage is adjustable through series rheostat **19.** A fixed resistor **18** and a rheostat **20** are series connected between the emitter of the transistor **16** and the gap to provide for selective control of cutting current being passed to the gap. A pulse generator, embodied as a multivibrator **22,** is used to provide selectively variable on-off time, variable frequency triggering pulses, i.e., drive signals, to the base of a drive stage transistor **24,** which in turn operates the output transistor **16.** Several types of multivibrators suitable for use in this type of electrical discharge machining power supply are shown and described in Lobur U.S. Pat. No. 3,243,567 issued on Mar. 29, 1966 and entitled "Electrical Discharge Machining Apparatus." While my invention is shown in connection with a transistorized EDM power supply, it is not so limited, but may be employed in any supply where an electronic switch, as I have defined it hereinabove, is connected betweeen a DC power source and the machining gap and periodically triggered into operation.

My servo control circuit has its reference voltage derived from a resistor network connected in shunt with the DC source **10.** The reference voltage network includes a fixed resistor **26** and a fixed resistor **28** connected in series with the variable resistor of a potentiometer **30.** A filter capacitor **32** is connected as shown. The control input for a differential amplifier type servo control circuit is taken from the drive signal output from the drive transistor **24** as shown. This signal is compared against the adjustable reference voltage set

by the potentiometer **30** to provide down-feed and backup of the servo feed means. Drive signal charges a capacitor **34** through a resistor **36** and a diode **38,** which diode is poled as shown. The diode **38** is further shunted by a resistor **40.** The connection of the drive signal sensing network is completed to the gap through a diode **42** whereby drive signal may be passed into the gap under conditions of output switch failure as will be explained hereinafter.

The direction of electrode movement is controlled by the direction of current flow through an electrically energized control element, in this case an electromagnetic servo valve coil **44** connected beteen the respective collectors of a transistor **46** and a transistor **48.** The full detail of the hydraulic motor and servo valve used are not shown herein in the interest of simplifying this disclosure. However, a number of suitable electro hydraulic EDM servo control systems are shown and described in Webb U.S. Pat. No. 3,230,412, issued on Jan. 18, 1966, entitled "Servo Feed Apparatus for Electrical Discharge Machining."

A pair of diodes **50'** are connected across the base-emitter junction of the transistor **46** to protect it from excess turn-off voltage. Similarly, a pair of diodes **52** are connected across the base-emitter junction of the transistor **48.** A third transistor **49** is coupled to the transistor **46** in emitter-follower arrangement with a protective diode **47** included. A pair of resistors **50** and **51** are connected in series with the emitter-collector of the transistor **49,** with the magnitude of the resistor **50** being substantially lower than that of the resistor **51.** The inclusion in the circuit of the transistor **49** makes possible the use of a high impedance input to the servo control circuit. During low current cutting operation, stable servo operation is assured. A rheostat **54** has its variable resistor connected between the collector of the transistor **48** and the right-hand terminal of the coil **44** to provide for adjustment for sensitivity of the servo operation. A parallel RC network is connected in series circuit between a fixed resistor **55** and the collector of transistor **46.** Included in the RC network are a resistor **64,** a resistor **65** and a capacitor **66.** A fast backup diode **67** is connected with the polarity shown. The resistor **65** is included in order to limit the discharge of the capacitor **66.** A pair of current limiting resistors **74** and **76** are connected in circuit with the respective bases of the transistors **46** and **48.** A load resistor **78** and a load resistor **80** are connected between the respective collectors of transistors **46** and **48** and the negative voltage terminal of the DC source **10,** while a single resistor **82** is coupled between the positive terminal of the DC source **10** and the emitters of the transistors **46, 48.**

The servo control circuit of FIG. **2,** similar to that of FIG. **1,** includes a reference voltage source which is derived from a main machining power source **110** by means of a shunt resistor network including a pair of fixed resistors **130, 132** and the variable resistance of potentiometer **134.** A filter capacitor **136** is connected as shown. The control element in the circuit is an electro-magnetic servo valve control coil **138.** The direction of electrode or of workpiece movement is controlled by the direction of current flow through the coil **138.** The full detail of the associated hydraulic motor and servo valve are not shown herein in the interest of simplifying this disclosure. However, a number of suitable electro hydraulic EDM servo control systems may be used as shown in the previously mentioned Webb U.S. Pat. No. 3,230,412. A potentiometer **150** is coupled as shown in parallel with the coil **138** to provide a velocity control for the servo feed. The coil **138** has its right-hand terminal operatively connected to the gap through a parallel resistor-capacitor network, including a resistor **156** and a capacitor **158** with resistor **156** being of a relatively high magnitude. The parallel resistor-capacitor network is coupled to the gap to sense gap conditions, which in turn provides an indication of whether the output transistor **16** is operating normally to pass machining power pulses across the gap. A resistor **160** and a rectifier **162** are connected across the resistor-capacitor network and the gap as shown.

DESCRIPTION OF OPERATION

With reference to FIG. **1,** when the power supply **10** and the multivibrator **22** are turned on, drive signals are passed from the transistor **24** to control the operation of the output transistor **16.** Machining power pulses are provided across the gap with precisely controllable frequency and on-off time factor. At the same time, the negative drive signal is passed through the resistor **36** and the diode **38** to be stored on the upper plate of the capacitor **34.** A portion of this drive signal will be passed to the gap through the diode **42.** The negative drive signal stored on the capacitor **34** provides turn-on of the transistor **49** and subsequent turn-on of the transistor **46.** Electron flow then occurs from the negative terminal of DC source **10** through the resistor **78,** the collector-emitter of the transistor **46** and through resistor **82** to the positive terminal of the DC source **10.** At the same time, electron flow occurs through the resistor **80,** rheostat **54,** in a leftward or down-feed direction through the coil **44,** through the resistors **55, 64** and through the collector-emitter of the transistor **46.** This electron flow in a leftward direction through coil **44** causes the electrode **12** to be advanced downwardly through the work **14.** During a shorted gap, the other transistor **48** will be turned on providing inter alia an electron flow through the coil **44** in a rightward or up-feed direction to withdraw the electrode **12** and move it upwardly away from the workpiece **14** to permit the short circuit condition to be cleared. It is further significant that during a short circuit condition with excessive current flow through the gap whether the condition is caused by output transistor **16** failure or by eroded particles bridging the gap, the electrode **12** is being withdrawn from the workpiece. At the same time, by reason of the sensing network used including the resistor **36,** the diode **42** and its connection to the gap, the drive signal is being virtually all passed to the positive gap terminal or ground. In the event a bank of output transistors **16** are used, bias source **17** will hold off the remainder of the transistors until the back-off occurs and the defective transistor has been replaced. This mode of operation furnishes both prompt and effective backup and gap current limiting at the same time.

An additional feature is that of the incorporation of the rheostat **54** network in series with the control coil **44.** This is important for stable servo action during high frequency cutting. During normal cutting, the hydraulic control coil **44** will pass current in one direction only and hold the gap constant according to the reference voltage setting previously made on the potentiom-

eter **30.** In the circuit of FIG. **1,** if the gap should short circuit, the capacitor **66** will discharge rapidly and provide fast ram backup, cutting away particles which may have been accumulated in the gap and in breaking up the short circuit condition. This provides highly effective pulsing of the gap during up-feed or down-feed and particularly improves deep hole cutting by clearing the shorted gap more quickly, thus preventing the electrode from backing out all the way.

The circuit of FIG. **2** is one which incorporates a servo back-off responsive to failure of the gap output transistor **16** or responsive to failure of the intermediate stage drive transistor **24.** Following the failure of an output transistor **16,** a number of related events take place. When transistor **16** fails in a shorted condition, this causes the gap to experience an abrupt rise in passage of current thereacross. Bias will be applied to the control electrodes of the other transistors **16** to hold them "off."

The sensing network comprising RC network **156–158** as has been mentioned incorporates a very large magnitude resistor **156** so that the capacitor **158** can only pass pulsating DC during the normal operation of the output transistor. Once there has been a failure of the output transistor **16,** there will be no down-feed signal available to control coil **138.** The reference signal, as preset by potentiometer **134,** will continue to pass a backup voltage through control coil **138** to backup the electrode or the workpiece as the case may be, one from the other, until the defective transistor **16** whether it be a single transistor or one of a bank of several transistors has been replaced.

It will thus be seen that I have provided an improved protective system for EDM in which responsive to failure of an output transistor there follows a hold-off of the other transistors in the output bank if there are more than one. My system at the same time and responsive to the same conditions provides backup of the electrode to eliminate any possible further damage to the gap elements through excessive current flow to the gap, and at the same time gives the operator a visual indication that a transistor failure has occurred.

I claim:

1. An electrical discharge machining apparatus having a bank of output electronic switches periodically operated by a drive signal switch for providing machining power pulses from a power source across a machining gap between an electrode and a workpiece, wherein a system is provided for electrode backup responsive to failure of at least one of said output switches, said system including a motive means and a servo feed circuit operatively connected to and controlling said motive means for providing a down-feed signal thereto during normal machining conditions, said servo feed circuit further operably connected to said output switches and operable responsive to their failure to interrupt said down-feed signal to said motive means and thereby increase the spacing of said gap for the duration of such failure.

2. In an electrical discharge machining apparatus having an output switch periodically operated by a drive signal switch for providing machining power pulses from a power source across a machining gap between a tool electrode and a workpiece, wherein the improvement comprises a backup system for providing increased spacing between said electrode and the workpiece responsive to failure of said drive signal switch, comprising a motive means and a servo feed circuit operatively connected to and controlling said motive means by providing a down-feed signal thereto during normal machining operation, said servo feed circuit operatively connected to the gap and to the drive signal switch to interrupt said down-feed signal to the motive means responsive to failure of said drive signal switch and thereby to increase the spacing of said gap.

3. In an electrical discharge machining apparatus having an output electronic switch periodically operated by a drive signal switch for providing machining power pulses from a power source across a machining gap between an electrode and a workpiece, wherein the improvement comprises a system for increasing the gap spacing to the top of the stroke responsive to failure of said output electronic switch, said system including a motive means and a servo feed circuit operatively connected to and controlling said motive means by providing a down-feed voltage signal thereto during normal machining operation, said servo feed circuit further operatively connected to the output switch and operable responsive to its failure to change the down-feed voltage signal to a voltage signal of backup polarity.

4. The combination as set forth in claim **3** wherein said motive means includes a reversible electro hydraulic motor and an electrical control means operatively connected and controlling the operation of said motor, said control means having a control voltage connectible to one of its terminals representative of failure of one of said output switches to provide increased spacing for the duration of such failure.

5. The combination as set forth in claim **3** wherein said motive means includes an electrically operated control means, said control means having one of its terminals connected to a reference voltage and the other of its terminals operatively coupled to said drive signal switch output for receiving a suitable voltage signal representative of failure of one of said output switches and for thereby increasing the spacing as between said tool electrode and workpiece.

6. In an electrical discharge machining apparatus having a plurality of parallel connected output electronic switches periodically turned on by a drive signal switch for providing machining power pulses from a power source across a machining gap between a tool electrode and a workpiece and further having a hold-off bias connected to the output switches for holding them off responsive to failure of one of their number, the improvement comprising a system for providing backup as between said tool electrode and workpiece subsequent to failure of one of said output switches, said system including a motive means and a servo feed circuit operable to provide a down-feed signal to said motive means during normal machining conditions, said servo feed circuit further operably connected to and operable responsive to failure of one of said output switches to interrupt the down-feed signal to said motive means and thereby increase the spacing of said gap, said motive means being of the electrohydraulic type and including a servo control coil and an operational amplifier operably connected to and controlling said coil, said operational amplifier having its one terminal connected to a reference voltage having a magnitude variable responsive to both gap voltage and to the failure of any one of said output switches.

7. In an electrical discharge machining apparatus having a plurality of parallel connected output elec-

tronic switches periodically turned on by a drive signal switch for providing machining power pulses from a power source across the machining gap between the tool electrode and workpiece, the improvement comprising a system for providing continued backup as between said tool electrode and workpiece subsequent to failure of at least one of said output switches, said system including a motive means and a sensing network coupled to one terminal of said gap for responding to pulsating DC voltage level, said servo feed further operable to provide a down-feed signal to said motive means during normal machining condition, said servo feed circuit coupled to said network and responsive to said DC voltage level resulting from failure of said output switch to interrupt down-feed to said motive means and to provide continued backup.

8. The combination as set forth in claim **7** wherein said sensing network comprises a rectifier and a parallel RC network combination, said combination coupled across said gap.

9. In an electrical discharge machining apparatus having a bank of output electronic switches periodically operated by a drive signal source for providing machining power pulses from the power source across a machining gap between a tool electrode and a workpiece, wherein a system is provided for continuous electrode backup responsive to failure of at least one of said output switches, said system including a motive means and a servo feed circuit operatively connected to and controlling said motive means for providing a down-feed signal thereto during normal machining conditions, said servo feed circuit further coupled to said output switches through a sensing network and operable responsive to voltage drop resulting from such failure to interrupt said normal down-feed signal to said motive means and therefore increase the gap spacing for the duration of such failure.

10. The combination as set forth in claim **9** wherein said network comprises a unilateral current conducting device connected in series combination with a parallel RC network, said combination coupled across said machining gap.

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